REMARKS

Claims 1, 2, 4-12, 14-19, 21-40, 43 and 44 are pending in the present application; claims 34-38 have been withdrawn and claims 3, 13, 20, 41 and 42 have been cancelled.

Claim Rejections under 35 U.S.C. 112

Claims 2 and 40 are rejected under 35 U.S.C. 112, first paragraph, as failing to comply with the written description requirements. This rejection is respectfully traversed.

How substantially a single optical mode or a few lower-order optical modes are contained in the first structure while the second structure extracts incoherent light from the first structure is clearly described in paragraphs [0005], [0006] and [0017]. The extraction of incoherent light is described in more detail in paragraph [0020].

Claim 33 has been revised and the revised claim 33 is believed to comply with 35 U.S.C. 112, first paragraph.

Claim Rejections under 35 U.S.C. 102

Claims 1, 2, 4, 5, 14-17, 28, 29, 31, 32, 39, 40 and 43 are rejected under 35 U.S.C. 102(b) as being anticipated by the article entitled "*Enhanced Coupling to Vertical Radiation Using a Two-Dimensional Photonic Crystal in a Semiconductor Light-Emitting Diode*," by Erchak et al. (Applied Physics Letters 78, 563-565 (2001)), referred to hereinafter as "Erchak." The rejection is respectfully traversed as applied to the claims as amended.

Claim 1 has been amended so that the first structure comprises two cladding layers wherein the active layer and the at least one waveguide layer are located between the two cladding layers. The at least one waveguide layer has an index of refraction higher than that of the cladding layers. The first structure forms a waveguide that traps the incoherent light generated by the active layer.

As amended, claim 1 clearly distinguishes from Erchak. Erchak clearly fails to teach or suggest at least one waveguide layer located between the two cladding layers along with the active layer. In the Office Action, the Examiner regards the DBR structure in Erchak to be the waveguide layer has an index of refraction higher than that of the cladding layers. As explained

below, the DBR structure of Erchak cannot be the waveguide layer. Furthermore, the DBR structure of Erchak is not between any two cladding layers.

Since the at least one waveguide layer has an index of refraction higher than that of the cladding layers, the at least one waveguide layer, the active layer and the two cladding layers form a waveguide structure, so that light generated by the active layer is trapped in the higher index material of the at least one waveguide layer between the two lower index cladding layers. This is not the case at all in Erchak. In Erchak, there is no waveguide layer which is sandwiched between two cladding layers along with the active layer.

Contrary to the opinion of the Examiner, the DBR structure of Erchak cannot be a waveguide layer. A Bragg reflector is typically made of alternating layers of high index of refraction materials and low index of refraction materials. Thus the DBR structure merely reflects light that is incident upon it in a normal or near normal direction, but absorbs or transmits light that is incident on the structure at angles tens of degrees away from the normal direction. Attached for the reference of the Examiner is a Wikipedia definition of DBR. For this reason, the DBR structure fails to trap light and is not suitable for a waveguide. If the Examiner disagrees, it is respectfully requested that the Examiner explain in detail and with factual support why in his view a DBR structure or layer can function as a waveguide. Attached for the reference of the Examiner is an article from the world wide web explaining optical waveguides. As clearly explained in the reference attached, an optical waveguide guides light by total internal reflection and typically includes a core and cladding surrounding the core, where the claddings are made of a material with a slightly lower index of refraction than the core. This difference in the indices causes total internal reflection to occur at a cladding/core interface. The DBR structure regarded by the Examiner as the waveguide clearly fails to match either the structure or function of the optical waveguides described in the reference attached.

As clearly explained in paragraph [0017] of the present application, in one embodiment, the waveguide layers 122 and 123 have the important function of trapping optical power along the waveguide in one single mode or a few lower-order modes. By confining the optical power to a single mode or a few lower-order modes, this renders the extraction by photonic crystal of the light emitted by the active layer particularly effective. As noted in paragraph [0017], "extraction by Photonic Crystal would not be effective if the waveguide supports a number of modes with quite different propagation constants because the band edge of PC structure may

correspond to only one mode or a few modes." Such feature is not taught or suggested by Erchak.

In the LED described by Erchak, since no waveguide layer is employed between cladding layers, the optical power generated by the quantum wells would be in many different modes so that the extraction of the optical power by photonic crystals is not particularly effective.

It is believed to be well settled that in order for a reference to anticipate a claim, there must be identity of elements between those of the reference and those of the claim. From the above, since Erchak has failed to describe at least one waveguide layer that is located between two cladding layers along with the active layer, where the at least one waveguide layer has a higher index of refraction than that of the cladding layers, Erchak fails to anticipate claim 1. Furthermore, there is no indication whatsoever suggesting a modification of the Erchak structure to include a waveguide layer between cladding layers along with the active layer.

In fact, it appears to be counter-intuitive to include a waveguide layer in between cladding layers in the LED device. Since the major problem known to those in the art in LED design is light extraction, and the function of a waveguide is normally to confine light within the waveguide structure, it is counter-intuitive to include a waveguide structure in an LED.

From the above, it is believed that claim 1 is not anticipated by Erchak and is non-obvious over Erchak as well.

As for claim 2, the Examiner is of the opinion that the active layer and the DBR structure in Erchak contain substantially a single optical mode on the ground that 935 nanometers and 799 nanometers into different embodiments are extracted from the structure. We respectfully disagree. First, the wavelength that is extracted from the first structure is different from the optical modes that may be present in the first structure. Thus, each of the 935 nanometer component and the 790 nanometer component that are extracted may have many different modes so that the fact that a single wavelength component may be extracted does not mean that only a single mode or a few lower order modes are extracted. In other words, wavelength of the light should not be confused with the optical modes. Second, what is extracted by the photonic crystal is only a part of the optical power present in the first structure. Hence the characteristics of the optical power extracted by the photonic crystal itself do not necessarily indicate what optical modes may be present in the first structure. If the Examiner disagrees, it is respectfully

requested that the Examiner explain in detail and with factual support why in his view the DBR and the active layer in Erchak contain only a single optical mode.

On claim 4, since the DBR layers of Erchak cannot be the waveguide layer, whatever may be the thickness of the layers of the DBR is irrelevant in regard to the thickness of the at least one waveguide layer of claim 4.

On claim 5, the Al_xO_y layer in Erchak is located below the active layer and is therefore not over the first structure which comprises the at least one waveguide layer, the active layer and two cladding layers.

In addition to the above, claims 2, 4, 5, 14-17, 28, 29, 31 and 32 are further believed to be allowable since they depend from allowable claim 1.

For substantially the same reasons as those explained above for claims 1 and 2, claims 39 and 40 are likewise believed to be allowable. Claim 43 is believed to be allowable since it depends from allowable claim 39.

Claim Rejections under 35 U.S.C. 103

Claim 1 contains the limitation that an index of refraction of said at least one waveguide layer is higher than that of the cladding layers. This further distinguishes from Erchak and the article entitled "*Resonant Cavity Light-Emitting Diode*," by Schubert et al., Five to Six Letters, 60 (8), 921-923 (1992) referred hereinafter as "Schubert." As explained above, a DBR is not suitable for use as a waveguide. Therefore the disclosure in Schubert in regard to DBR layers has no bearing on the issue of the index of refraction of the at least one waveguide layer in claim 1. Claims 3, 6-12, 18, 19, 21-27 and 43-44 are believed to be allowable since they depend from allowable claims.

The claims have now been amended to require that the light emitting diode device outputs incoherent light. The claims therefore differentiate from U.S. Patent 6,704,343 to Deng et al.

CONCLUSION

In view of the amendments and remarks contained herein, it is believed that all pending claims are in condition for allowance and an indication of their allowance is requested.

However, if the Examiner is aware of any additional matters that should be discussed, a call to the undersigned attorney at: (415) 318-1162 would be appreciated.

Respectfully submitted,

James S. Hsue
Reg. No. 29,545

May 19, 2006
Date

PARSONS HSUE & de RUNTZ LLP
595 Market Street, Suite 1900
San Francisco, California 94105
Telephone: 415.318.1160 (main)
Telephone. 415.318.1162 (direct)
Fax: 415.693.0194

Distributed Bragg reflector

From Wikipedia, the free encyclopedia

In guided wave optics, a **distributed Bragg reflector (DBR)** is a structure formed from multiple layers of alternating materials with varying refractive index, or by periodic variation of some characteristic (such as height) of a dielectric wave guide, resulting in periodic variation in the effective refractive index in the guide. Each layer boundary causes a partial reflection of an optical wave, and for waves with optical wavelength such that the many reflections combine with constructive interference, a high quality reflector is formed.

Distributed Bragg reflectors are critical components in vertical cavity surface emitting lasers and other types of narrow-linewidth laser diodes. They are also used to form an optical cavity in fiber lasers.

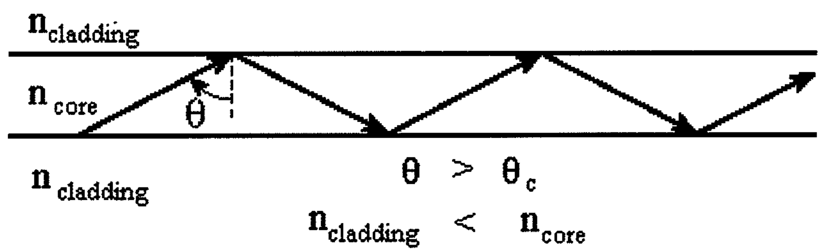
See also

- Dielectric mirror

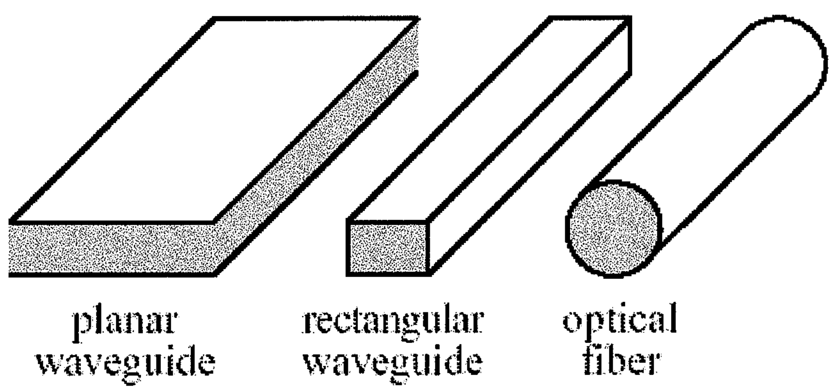
Categories: Optics stubs | Optics | Fiber optics

An optical wave guide is a structure that "guides" a light wave by constraining it to travel along a certain desired path. Usually the light is guided by total internal reflection (TIR). TIR occurs when light is incident on a dielectric interface at an angle greater than the critical angle θ_c.

A wave guide traps light by surrounding a guiding region, called the core, made from a material with index of refraction n_{core}, with a material called the cladding, made from a material with index of refraction $n_{cladding} < n_{core}$. Light entering is trapped as long as $\sin\theta > n_{cladding}/n_{ncore}$.

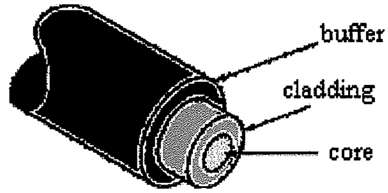


Light can be guided by planar or rectangular wave guides, or by optical fibers.



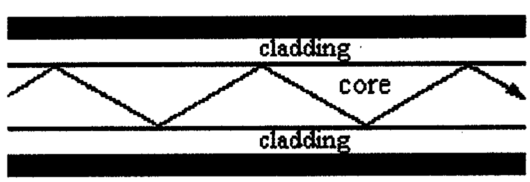
An optical fiber consists of three concentric elements, the core, the cladding and the outer coating, often called the buffer. The core is usually made of glass or plastic. The core is the light-carrying portion of the fiber. The cladding surrounds the core. The cladding is made of a material with a slightly lower index of refraction than the core. This difference in the indices causes total internal reflection to occur at the core-cladding

boundary along the length of the fiber. Light is transmitted down the fiber and does not escape through the sides of the fiber.



- Fiber Optic Core:
  - the inner light-carrying member with a high index of refraction.
- Cladding:
  - the middle layer, which serves to confine the light to the core. It has a lower index of refraction.
- Buffer:
  - the outer layer, which serves as a "shock absorber" to protect the core and cladding from damage. The coating usually comprises one or more coats of a plastic material to protect the fiber from the physical environment. Sometimes metallic sheaths are added to the coating for further physical protection.

Light injected into the fiber optic core and striking the core-to-cladding interface at an angle greater than the critical angle is reflected back into the core. Since the angles of incidence and reflection are equal, the light ray continues to zig-zag down the length of the fiber. The light is trapped within the core. Light striking the interface at less than the critical angle passes into the cladding and is lost.



Problems:

- For 589nm light, calculate the critical angle for the following materials surrounded by air.
  (a) diamond, n = 2.419
  (b) flint glass, n = 1.66
  (c) ice, n = 1.309
  - Solution:
    $\sin\theta_c = n_2/n_1$. For air, $n_2 = 1$, so $\sin\theta_c = n_2/n_1$
    - (a) diamond: $n_1 = 2.419$, $\sin\theta_c = 0.41$, $\theta_c = 24.42^o$.

- (b) flint glass: $n_1 = 1.66$, $\sin\theta_c = 0.60$, $\theta_c = 37.04^o$.
- (c) ice: $n_1 = 1.309$, $\sin\theta_c = 0.76$, $\theta_c = 49.81^o$.

- An optical fiber is made of a clear plastic for which the index of refraction is 1.5. For what angles with the surface does light remain contained within the fiber?
  - Solution:

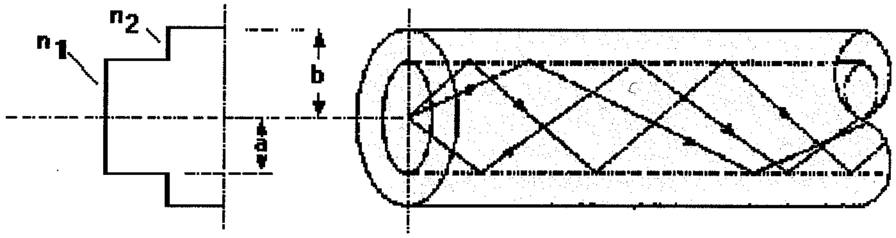
    $n_1 = 1.5$, $\sin\theta_c = 0.67$, $\theta_c = 41.8^o$.

    For angles greater that 41.8^o with respect to the normal or for angles smaller than $90^o - 41.8^o = 48.2^o$ with respect to the surface the light remains contained within the fiber.

Optical fibers usually are specified by their size. Usually the outer diameter of the core, the cladding and the buffer are specified. For example, 62.5/120/250 refers to a fiber with a 62.5 μm diameter core, a 120 μm diameter cladding and a 0.25 mm outer coating diameter.

The laws governing the propagation of light in optical fibers are Maxwell's equations. When information about the material constants, such as the refractive indices, and the boundary conditions for the cylindrical geometry of core and cladding is incorporated into the equations, they can be combined to produce a wave equation that can be solved for those electromagnetic field distributions that will propagate through the fiber. These allowed distributions of the electromagnetic field across the fiber are referred to as the modes of the fiber. They are similar to the modes found in microwave cavities and laser cavities. When the diameter of the core is large compared to the wavelength of the light propagating through the fiber, then the number of allowed modes becomes large and ray optics gives an adequate description of light propagation in fibers. Those fibers are called **multimode fibers**.

Multimode fibers for which the refractive index of the core is a constant and the index changes abruptly at the core-cladding interface are called **step-index fibers**.



MULTIMODE STEP-INDEX FIBER

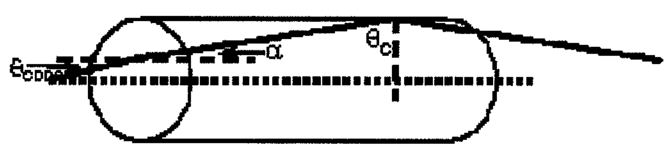
For such fibers the fractional refractive index difference is given by

$$\Delta = (n_{core}-n_{cladding})/n_{core}.$$

The cone angle θ_{cone} of the cone of light that will be accepted by an optical fiber with a fractional index difference Δ is given by

$$n_i \sin\theta_{cone} = (n_{core}^2 - n_{cladding}^2)^{1/2}$$

Here n_i is the index of refraction of the material from which the light is entering the fiber.



$\sin\theta_c = n_{cladding}/n_{core} = \cos\alpha = (1 - \sin^2\alpha)^{1/2}.$
$n_{core}*\sin\alpha = (n_{core}^2 - n_{cladding}^2)^{1/2}.$
Snell's law: $n_i \sin\theta_{cone} = n_{core}*\sin\alpha$

The numerical aperture (NA) is the measure of of how much light can be collected by an optical system. For a fiber, it is defined as n_i times the sine of the maximum angle at which light rays can enter the fiber and be conducted down the fiber. It is given by $NA = (n_{core}^2 - n_{cladding}^2)^{1/2}$.

When $\Delta << 1$, this can be approximated by

$$NA = ((n_{core} - n_{cladding})(n_{core} + n_{cladding}))^{1/2} = (2n_{core}^2\Delta)^{1/2} = n_{core}(2\Delta)$$

The condition $\Delta << 1$ is referred to as the weakly-guiding approximation.

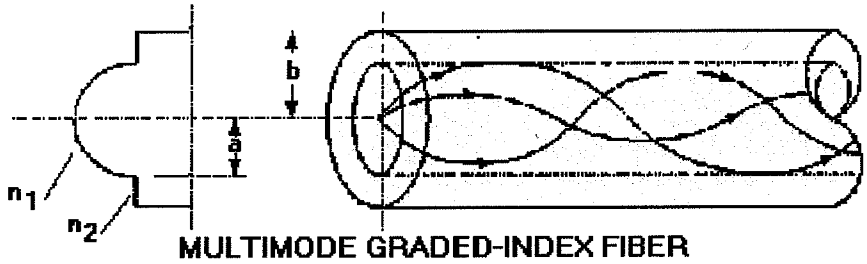
Each mode in a step-index multimode fiber is associated with a different entrance angle. Each mode therefore travels along a different path through the fiber. Different propagating modes have different group velocities. As an optical pulse travels down a multimode fiber, the pulse begins to spread. Pulses that enter separated from each other will eventually overlap each other. This limits both the bandwidth of a multimode fiber and the distance over which it can transport data.

Bandwidth measures the data-carrying capacity of an optical fiber. It is expressed as the product of the data frequency and the distance over which data can be transmitted at that frequency. For example a fiber with a bandwidth of 400 MHz km can transmit data at a rate of 400 Mhz for 1 km or at a rate of 20 MHz for 20 km. Step-index fibers have a typical bandwidth of 20 MHz km.

Step-index fibers are available with core diameters of 100 to 1000 μm. They are well suited to applications requiring high-power densities, such delivering laser power for medical and industrial applications.

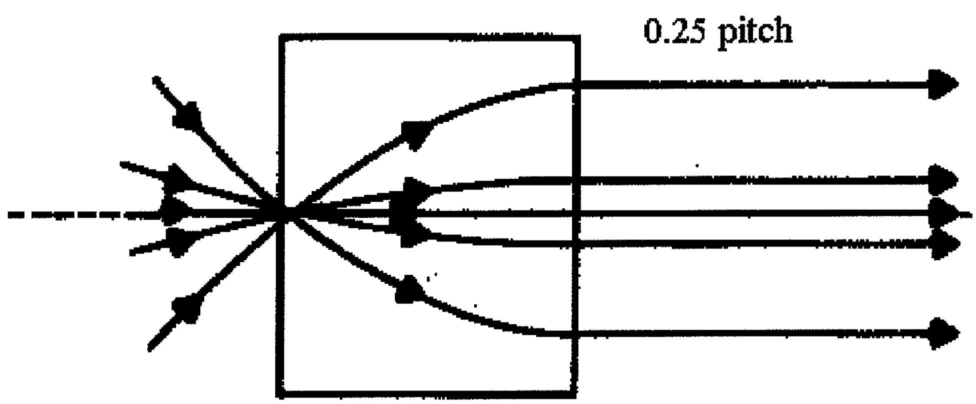
The smearing of the pulses in step-index fibers scan be reduced through the use of graded-index or single-mode fibers.

The core in a **graded-index fiber** has an index of refraction that decreases as the radial distance from the center of the core increases. As a result, the light travels faster near the edge of the core than near the center. Different modes therefore travel in curved paths with nearly equal travel times. This greatly reduces modal dispersion in the fiber. Graded-index fibers therefore have bandwidths which are significantly greater than step-index fibers. Typical core diameters of graded-index fibers are 50, 62.5 and 100 μm. Graded-index fibers are often used in medium-range communications applications, such as local area networks. Graded-index fibers have a typical bandwidth of 500 MHz km at λ = 1300 nm and 160 MHz km at λ = 850 nm.

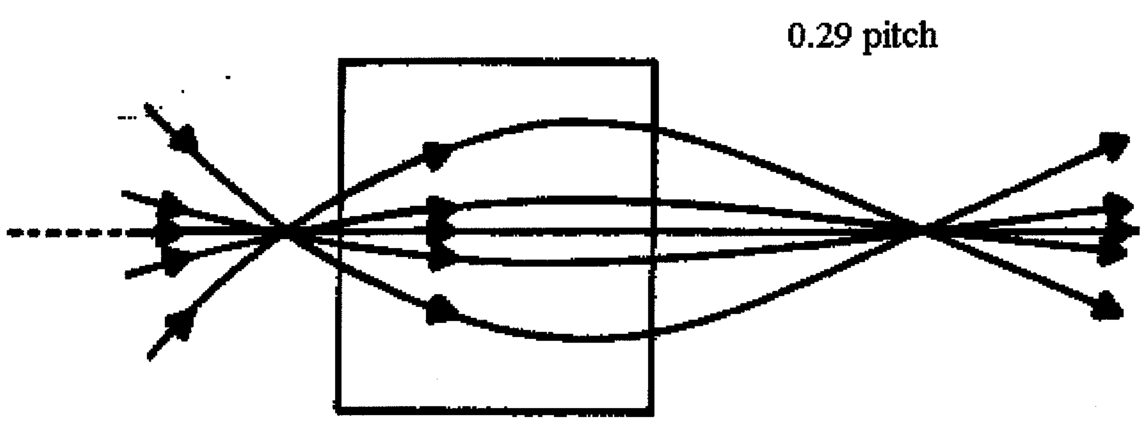


A fan of rays injected into a graded-index fiber is brought back into focus, before it diverges again. A ray will travel along an approximately sinusoidal path. The wavelength of this sinusoidal path is called the pitch of the fiber. The pitch is determined by Δ, the fractional index difference.

If a graded-index fiber is cut to have a length of one quarter of the pitch of the fiber, it can serve as an extremely compact lens, called a **GRIN lens**.



Light exiting a fiber can be collimated into a parallel beam when the output end of the fiber is connected to the GRIN lens. Because its properties are set by its length, this graded-index lens is referred to as a quarter-pitch or 0.25 pitch lens.



Focusing of the fiber output onto a small detector or focusing of the output of a source onto the core of a fiber can be accomplishing by increasing the length of the GRIN lens to 0.29 pitch. Then the source can be moved back from the lens and the transmitted light can be refocused at some point beyond the lens. Such an arrangement is useful for coupling sources to fibers and fibers to detectors.

The modes that propagate in a fiber are found by solving Maxwell's equation for the electric field of the light in the fiber in cylindrical coordinates. Solutions which are harmonic in space and time, are of the form

$$E(r,\phi,z) = f(r)\cos(\omega t - \beta z + \chi)\cos(q\phi)$$

where ω is the angular frequency of light and β is the propagation constant. Here z is the direction of propagation, and q is an integer.

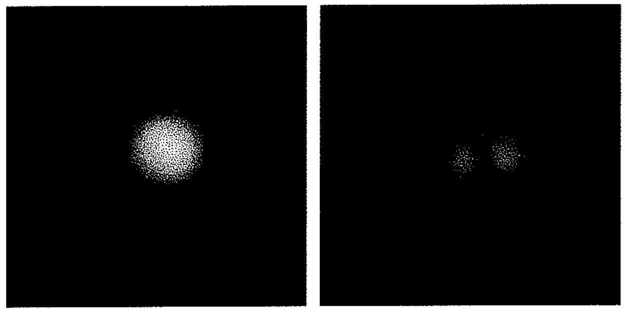
The group velocity of the mode is β/ω. It is important to make the distinction between the magnitude of the wave vector, k, and the magnitude of propagation constant β. In the ray approximation, β is the z-component of **k**.

The normalized wave number, or V-number of a fiber is defined as $V = k_f\, a$ NA. Here k_f, is the free space wave number, $2\pi/\lambda_0$, a is the radius of the core, and NA is the numerical aperture of the fiber. Many fiber parameters can be expressed in terms of V. For example, the number of guided modes n in a step-index multimode fiber is given by $V^2/2$ for $n >> 1$, and a step index fiber becomes single-mode for a given wavelength when $V < 2.405$.

In the weakly-guiding approximation ($\Delta << 1$), the modes propagating in the fiber are linearly polarized (LP) modes characterized by two subscripts, m and n. The first subscript, m, gives the number of azimuthal, or angular, nodes in the electric field distribution. The second subscript, n, gives the number of radial nodes. Output patterns are symmetric about the center of the beam and show bright regions separated by dark regions (the nodes that determine the order numbers m and n). The zero field at the outer edge of the field distribution is counted as a node.

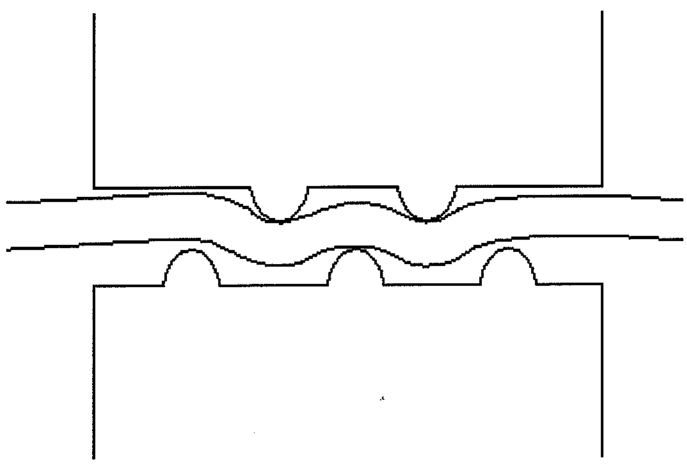
When the V number is less than 2.405 only the LP_{01} mode propagates. When the V number is greater than 2.405 the next linearly-polarized mode

can be supported by the fiber, so that both the LP_{01} and LP_{11}, modes will propagate.



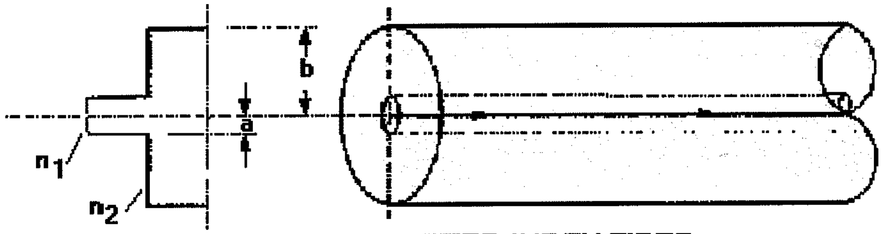
LP_{01} LP_{11}

Multimode fibers used for telecommunications have V-numbers between ~50 or 150. A large number of modes are supported by these fibers. The amount of light carried by each mode is determined by the launch conditions. The attenuation of some large-angle modes is much higher than that of other modes, but after the light has propagated a considerable distance, a stable mode distribution develops. To generate a stable mode distribution even with only a short length of fiber, mode filtering is accomplished through **mode scrambling**.



A series of bends is introduced into the fiber. These bends couple out the light in the large-angle modes with the high attenuation and distribute the remaining light among the other guided modes. Mode scrambling permits repeatable, accurate measurements of fiber attenuation to be made in the laboratory, even with short lengths of fiber.

Only the fundamental zero-order mode is transmitted in a **single mode fiber**.



SINGLE MODE STEP-INDEX FIBER

Because the single-mode fiber propagates only the fundamental mode, modal dispersion, the primary cause of pulse overlap, is eliminated. Thus, the bandwidth of a single-mode fiber is much higher than that of a multimode fiber. Pulses can be transmitted much closer together in time without overlap. Because of this higher bandwidth, single-mode fibers are used in all modern long-range communication systems. Typical core diameters are between 5 and 10 μm. Single-mode fibers have a typical bandwidth of 100 GHz km.

Signals lose strength as they propagate through the fiber. This is known as beam attenuation. **Attenuation** is measured in decibels (dB).

$$A(dB) = 10 \log_{10}(P_{in}/P_{out}) \text{ or } 10^{(A/10)} = P_{in}/P_{out}. \; P_{out} = 10^{-(A/10)} P_{in}$$

P_{in} and P_{out} refer to the optical power going in and coming out of the fiber. The table below shows the power typically lost in a fiber for several values of attenuation in decibels.

Attenuation (dB)	Power Loss (%)
10	90
3	50
0.1	2

The attenuation of an optical fiber is wavelength dependent. Attenuation is usually expressed in dB/km at a specific wavelength. Typical values range from 10 dB/km for step-index fibers at 850 nm to a few tenths of a dB/km for single-mode fibers at 1550 nm. There are several causes of attenuation in an optical fiber

- Rayleigh Scattering — Microscopic-scale variations in the index of refraction of the core material can cause considerable scatter in the beam leading to substantial losses of optical power.
- Absorption — Current manufacturing methods have reduced absorption caused by impurities to very low levels.

- Bending — Manufacturing methods can produce minute bends in the fiber geometry. Sometimes these bends will be great enough to cause the light within the core to hit the core/cladding interface at less than the critical angle so that light is lost into the cladding material. This also can occur when the fiber is bent in a tight radius. Bend sensitivity is usually expressed in terms of dB/km loss for a particular bend radius and wavelength.

Links:

- Fiber Optics
- How are fibers made?